# Final Report
**of the**
# Joint Fire Science Rapid Response Project

# "Real-Time Evaluation of Effects of Fuel-Treatments and Other Previous Land Management Activities on Fire Behavior during Wildfires

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***Crown Fire Behavior on the Black Mountain II Fire, August 2003***

# Final Report: Real-Time Evaluation of Effects of Fuel-Treatments and Other Previous Land Management Activities on Fire Behavior during Wildfires

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### Abstract

Hazardous fuels reduction work and past land-use activities must be measured for effectiveness during a wildfire event. This report summarizes the accomplishments and findings of work completed to measure pre-, during, and post-burn conditions during the Summer and Fall 2003. Nine fires were visited and evaluated in Montana and California. Plot were chosen in untreated and treated (i.e., fuel treatment, other past land use activities, or old fires) sites in the fires path and pre-measurements were taken and data recorders were set up. The team was successful in recording one fire's path through two sites, including active crown fire behavior. We summarize the measured fuels, fire behavior and resulting effects of this fire that is excerpted from a manuscript in final stages of preparation for publication. Although a small amount of data was captured, there are some important implications for fuel treatments and fire behavior model applications used in planning fuel treatments. We found that rates of spread were greater in a dense stand than in an open stand, despite much greater 1-hour fuel loading in the open stand. This suggests that assumptions on linkages between surface and crown fire components of such widely used models as FARSITE need to continue to be investigated. Secondly, although fire behavior was less intense on the open site, the patch extended across a small portion of the landscape. This suggests that the size of fuel treatment areas is important, particularly under high or extreme weather and fire behavior conditions in order for the fuel treatment to be effective in changing fire behavior. Once more replicates are obtained, we will be better able to address the question of how intensive does a treatment need to be to significantly affect fire behavior. Extensive technology transfer has been conducted, particularly with fire managers.

## 1. Introduction

This is the final report of the accomplishments and findings of the Joint Fire Science Rapid Response Project "Real-Time Evaluation of Effects of Fuel-Treatments and Other Previous Land Management Activities on Fire Behavior during Wildfires". The primary objective was to prototype in-situ measurements during wildfires of changes in fire behavior through fuel treatments, past land-use activities or old fires. Key elements of the prototype, in addition to the scientific objectives, were: working successfully with incident management teams on the active parts of fires, equipment and sensor operation and design, and operational procedures and methods for collecting data.

Our specific objectives were to:

1) Directly measure the effects of fuel treatments at the site and landscape scales on fire behavior during wildfires.

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2) Compare effects of different types and degrees (intensity and landscape extent) of fuel treatments or other past land-use activities (such as, timber harvest) on fire behavior at the site and landscape scales.

3) Improve our understanding and modeling of the relationships between measurements of crown fuels and fire behavior.

Our approach was to find fuel treatments, past land-use activity or old fires in the path of wildfires and to obtain fuel measurements and set up fire behavior sensors ahead of the fire.

## 2. Methods

The primary fire behavior responses included: rate of spread, temperature, heat flux (total, radiant, and by subtraction convective), fire type (surface, passive or active crown), flame geometry and fireline intensity. Figure 1 shows a crew completing measurements, pre-burn at a site. We worked closely with Incident Management teams in the development of procedures to use in interfacing with the teams. All team members were minimally arduous firefighter II qualified. The team included a minimum of two Division Supervisor qualified operations on most tours.

Figure 1. Measurements being taken at a site, pre-burn.

## 3. Results and Accomplishments

### *3.1. Field Accomplishments on Fires*

The wildfire behavior rapid response team, led by principal investigator Jo Ann Fites and fire behavior analyst Carol Henson, evaluated and visited nine fires in the summer and fall of 2003. The team had four tours, spending a total of 45 days on fires. Most fire locations were in

Montana and the remainder in California. The team found sites with fuel treatments, past land-use activities (timber harvest), or old fires suitable for the project objectives on all but one fire. Fire behavior and associated fuels data were collected on two of the fires. This included high intensity, rapid crown fire on one fire. Table 1 is a summary of the nine fires visited and evaluated by the wildfire behavior rapid response team.

**Table 1.** Summary of fires evaluated by the wildfire behavior rapid response team.

| **Fire** | **Location** | **Targeted Sample Site** | **Data Collected** |
|---|---|---|---|
| Salt | Eldorado National Forest, CA | Thinned and burned fuelbreak | No – fire did not reach site |
| Hidden Lake | Bearverhead Deerlodge National Forest, MT | None suitable | Fire determined not suitable |
| Black Frog Complex | Bearverhead Deerlodge National Forest, MT | Selective harvest | Rain came and fire was not likely to reach site |
| Wedge | Flathead National Forest & Glacier National Park, MT | Fuel break around community & harvest area on private property | Fuel break had already burned, site on private land not suitable |
| Robert | Flathead National Forest & Glacier National Park, MT | Moose burn from 2000 | Sensors pulled after being in place for 1 week and substantial rain. Several days later, fire blew through site. Data was collected on one site as part of a burnout operation below Apgar lookout—sensor placement test. |
| Crazy Horse | Flathead National Forest, MT | Shelterwood and clearcut on Plum Creek Timber lands | Sensors pulled after being in place for over 1 week, rain occurred and fire not likely to reach sites. |
| Black Mountain II | Lolo National Forest, MT | Contrasting open and closed forests | Sensors moved from one site after fire burned with slow backing fire near but not to sites; 2nd site experienced active crown fire. |
| Cod | Tahoe National Forest, CA | Adjacent thinned and unthinned areas | Fire activity low and did not reach site. No treatments in canyon where more active fire behavior occurred. |
| Old | San Bernadino National Forest, CA | Treated and untreated areas in wildland urban interface | Weather change moderated fire by the time we were able to safely set up. |

For the Robert fire, an untreated site and a treated site within the Moose burn (occurred in 2000) were chosen. Figure 2 shows the untreated site and Figure 3 shows the site that was within an old burn (Moose burn). On the Crazy Horse fire, timber stands of untreated (Figure 4) and thinned sites (Figure 5) were chosen.

Figure 2. Untreated site within the Robert Fire, Montana (pre-burn).


Figure 3. Treated site (Moose burn) within the Robert Fire, Montana (pre-burn).


Figures 4 and 5. Unthinned and thinned areas within the Crazy Horse fire, Montana (pre-burn).

After limited success in collecting fire behavior through fuel treatments or past land use activities on 6 of the 7 fires, the team decided to adjust strategies on the Black Mountain II fire, in Montana, to increase the probability of data capture. To do this, we looked for sites closer to the active fireline that had contrasting fuels. One of the sites had conditions that were similar to an area treated by thinning, an open pine stand (Figure 6). The second, adjacent stand, was a dense Douglas-fir dominated site that was greatly contrasting in surface fuel and crown fuel loading (Figure 7).

Figure 6. Open, pine-dominated stand (similar to a thinned site), Black Mountain II fire, Montana (pre-burn)

Figure 7. Dense, untreated Douglas-fir stand, Black Mountain II fire, Montana (pre-burn).

During the set-up of the plots, smoke was observed on the slope below at the base of the drainage. Later that afternoon, the fire burned with active crown fire behavior through the sites. Figure 8 shows the crown fire behavior in the dense, untreated Douglas-fire plot. Temperatures exceeded 1900 degrees C on one sensor. Extensive footage of active crown fire behavior was collected in addition to rate of spread and heat flux. Figure 9 shows the post-burn area in the Douglas-fir plot.

Figure 8. Crown fire through the dense, untreated Douglas-fir site, Black Mountain II fire, Montana.

Figure 9. Post burn conditions on the dense, untreated Douglas-fir site, Black Mountain II fire, Montana.

### *3.2. Results and Pending Publication*

A manuscript is in the final stages of preparation for publication based upon the data collected on the Black Mountain II fire. It is titled "In-Situ Measurement of Fire Behavior during a Crown Wildfire in Relation to Fuels: a Case Study on the Black Mountain II Fire, Montana USA" and will be submitted to International Journal of Wildland Fire. Below is a summary of some of the information from the manuscript.

#### 3.2.1. Fuel Loading and Configuration

Canopy bulk density was 0.29 $kg/m^3$ at the dense site and less than half that at the open site, at 0.12 $kg/m^3$. Understory and surface fuels were greater in the open site at 24 $kg/m^2$ than at the dense site at 14 $kg/m^2$. The distribution of fuels by size and type differed as well. The dense site had a greater proportion of 10- and 1000- hour fuels, whereas the open site had a greater proportion of 1-, 10-hour fuels and dead grass. Table 2 summarizes the pre-burn forest structure and Table 3 summarizes the fuel loading by type and size class, for pre and post-fire conditions, for the two sites recorded on the Black Mountain II fire.

**Table 2.** Pre-burn forest structure in the Black Mountain II fire.

| Stand | Attribute | |
|---|---|---|
| Open | Height (m) | 15.58 |
| | dbh (cm) | 29.00 |
| | Density (trees/ha) | 726.00 |
| | Canopy base height (m) | 2.43 |
| | Crown Bulk Density ($kg/m^3$) | 0.12 |
| | Basal area ($m^2$) | 13.47 |
| Dense | Height (m) | 15.28 |
| | dbh (cm) | 24.00 |
| | Density (trees/ha) | 1159.00 |
| | Canopy base height (m) | 6.10 |
| | Crown Bulk Density ($kg/m^3$) | 0.29 |
| | Basal area ($m^2$) | 17.65 |

**Table 3**. Fuel loading by type and size class for pre and post-fire conditions. The proportion of consumption during the flaming front passage was estimated from the video footage. "frctn flaming" is the assumed fraction of total consumption that is assumed to take place in the flaming front. "flaming" is that multiplied by the estimated total consumption, which gives the estimate of fuel consumption in the flaming front.

| DENSE SITE | pre | post | total | frctn flam | flaming | |
|---|---|---|---|---|---|---|
| duff | 8.39 | 0 | 8.4 | 0.0 | 0.0 | kg/m2 |
| litter | 1.78 | 0 | 1.8 | 0.1 | 0.2 | kg/m2 |
| grass/herb | 1.01 | 0 | 1.0 | 1.0 | 1.0 | kg/m2 |
| shrub | 0.29 | 0.05 | 0.2 | 0.1 | 0.0 | kg/m2 |
| 1-hr load | 0.12 | 0 | 0.1 | 1.0 | 0.1 | kg/m2 |
| 10-hr load | 0.68 | 0 | 0.7 | 0.1 | 0.1 | kg/m2 |
| 100-hr load | 0.3 | 0 | 0.3 | 0.0 | 0.0 | kg/m2 |
| 1000-hr load | 1.28 | 0.2 | 1.1 | 0.0 | 0.0 | kg/m2 |
| canopy fuel load | 1.33 | 0 | 1.3 | 1.0 | 1.3 | kg/m2 |
| TOTAL | 15.2 | 0.3 | 14.9 | 3.3 | 2.7 | kg/m2 |

| | | | | consumption | | |
|---|---|---|---|---|---|---|
| **OPEN SITE** | **pre** | **post** | **total** | **frctn flam** | **flaming** | |
| duff | 14.87 | 0 | 14.9 | 0.0 | 0.0 | kg/m2 |
| litter | 5.07 | 0 | 5.1 | 0.1 | 0.5 | kg/m2 |
| grass/herb | 1.83 | 0 | 1.8 | 1.0 | 1.8 | kg/m2 |
| shrub | 1.41 | 0.05 | 1.4 | 0.1 | 0.1 | kg/m2 |
| 1-hr load | 0.03 | 0 | 0.0 | 1.0 | 0.0 | kg/m2 |
| 10-hr load | 0.21 | 0 | 0.2 | 0.1 | 0.0 | kg/m2 |
| 100-hr load | 0.27 | 0 | 0.3 | 0.0 | 0.0 | kg/m2 |
| 1000-hr load | 0 | 0 | 0.0 | 0.0 | 0.0 | kg/m2 |
| canopy fuel load | 0.79 | 0 | 0.8 | 1.0 | 0.8 | kg/m2 |
| TOTAL | 24.5 | 0.1 | 24.4 | 3.3 | 3.3 | kg/m2 |

3.2.2 Type of Fire

Both sites displayed crown fire behavior. All fine canopy fuels were consumed on both the dense and open sites. The dense site appeared to have a solid "wall" of flame from the surface up through the canopy, indicative of an active crown fire. The camera on the open site was not directed at the canopy and we do not know the type of crown fire.

3.2.3. Fireline Intensity

Fireline intensity was calculated from estimates of flame front spread rate and fuel consumption in the flaming front (Alexander 1982, Byram 1959).

Because heat content was a constant 18700 kJ/kg in all calculations, differences in intensity values result from variation in rate of spread and fuel consumption. The dense site had a spread rate 2.4 times that of the open site (73 vs. 31 m/min, Table 4), but lower amounts of total (14.9 vs. 24.4 kg/m2; 61%, Table 3) and flaming fuel consumption (82%). The combination of those differences in the intensity calculations leads to fireline intensity 2 times higher and fire intensity 1.4 times higher at the dense site than the open site (Table 4).

Fire intensity was 5.5 times higher than Byram's fireline intensity at the dense site, 7.4 times higher at the open site (Table 4). The large difference between Byram's fireline intensity and frontal fire intensity is the inclusion of duff and coarse woody loads in the frontal fire intensity calculation.

**Table 4.** Byram's fireline intensity and frontal fire intensity for the dense and open sites at the Black Mountain II fire.

| | ***Dense site*** | ***Open site*** |
|---|---|---|
| ***Rate of spread (m/min)*** | 73 | 31 |
| ***Byram's fireline intensity (kW/m)*** | 62,282 | 32,018 |
| ***Fire intensity (kW/m)*** | 340,613 | 236,035 |

*Heat flux* – Maximum total heat flux measured was 250 KW/m$^2$, which lasted for approximately 10 seconds. Convective heat exceeded radiant heat during the 20 seconds of higher measurements (Table 5). After 30 seconds, the wires apparently burned and no additional data was collected, although the video showed active burning for at least 30 minutes, including passing firewhirls for the first 10 minutes.

**Table 5**. Comparison of measured radiant heat flux, total heat flux, and calculated convective heat flux on the Black Mountain II fire.

| Time Interval (seconds) | Radiant Heat Flux | Convective Heat Flux (kW/m$^2$) | Total Heat Flux |
|---|---|---|---|
| 8 | 83.2 | 147.7 | 230.9 |
| 12 | 69.8 | 124.9 | 194.7 |

*Temperature* – Temperatures exceeded the duration of heat ratings of the thermocouples, 1000$^{o}$C, reaching a peak of 1880 $^{o}$C within the first several minutes of measurements, at the dense site. Therefore, we are unable to verify the temperature of 1880 $^{o}$C. After 2 to 4 minutes, the lead wires and/or thermocouples were burned and no additional data was collected.

3.2.4. Rate of Spread - Comparison with Fire Behavior Prediction Models

NEXUS simulations for the open site, assuming nominal 20-ft wind of 10 mi/hr, indicate passive crown fire with final spread rate of 5-15 m/min (depending on whether average or maximum spread rate is used). Observed spread rate was 18.3 m/min.

For the dense site, NEXUS predicts conditional crown fire with possible crown fire spread rates of 43 – 72 m/min, depending on whether the average or maximum spread rate is used. Observed spread rate was 73.2 m/min. By contrast, if the fire reached the site as a surface fire, NEXUS predicts spread rate would be only 2.8 m/min.

At both the open and dense sites, the best spread rate results with NEXUS were obtained using Rothermel's maximum spread rate model rather than the average.

Assuming fire spread into the sites as a crown fire, as occurred at Black Mountain II fire, then NEXUS predicts the dense site will exhibit higher fireline intensity than the open site at all windspeeds. However, FLIN (fireline intensity), at both sites, is significantly underpredicted compared to the observed. Because spread rate was only slightly underpredicted, the source of error for FLIN is in W, the weight of fuel consumed in the flaming front. In NEXUS, W is the canopy fuel load plus surface fuel consumed. Canopy fuel load is the same, in both observed and predicted calculations; therefore, the main difference in FLIN results from the estimate of surface fuel consumption in the flaming front. The observed Wsurface was based on estimated flaming fuel consumption, whereas NEXUS is based on calculated reaction intensity and flaming duration. Both could be in error.

The implicit Wsurface in NEXUS is 0.86 kg/m2 for the dense stand and 0.78 kg/m2 for the open stand. By contrast, estimated actual Wsurface was 1.4 kg/m2 in the dense stand and 2.5 kg/m2 in the open stand. The grass/herb component alone was 1.0 kg/m2 at the dense site and 1.8 kg/m2 at the open site, greater than the total estimated Wsurface from NEXUS.

NEXUS derives Wsurface from the surface fuel model, not actual surface fuels. The surface fuel model is calibrated to give reasonable predictions of spread rate, with no consideration given to the accuracy of Wsurface, an ancillary calculation.

3.2.5. Implications for Management and Fire Behavior Prediction Models

Although both sites exhibited intense crown fire behavior, there were some findings that have implications for both fuel treatments and fire behavior prediction models that are used extensively in fire and land-use management planning. First, rates of spread of spread were lower in the more open stand, despite the prevalence of higher levels of 1-hour fuels that current fire behavior models emphasize for surface rate of spread. This suggests that relative importance of crown fuels in determining rate of spread of crown fires and linkage of crown fuels with surface fuels may differ than currently predicted in fire behavior models. FARSITE is based on assumptions that surface rate of spread in dependent crown fires comes from Anderson fuel model 10. Perhaps multiple assumptions for surface models are needed or different means for linking surface and crown fire behavior models are needed.

Secondly, although the open stand was selected as a "proxy" for a thinned stand, it was a fairly small patch in a landscape otherwise more similar to the dense Douglas-fir site. It is apparent that when a fire has built up "steam" coming from the bottom of a steep slope to the top, that it will take a fairly wide or large fuel treatment to affect change in fire behavior. This has important implications for fuel breaks or defensible fuel profile zones that are usually of limited width and often in similar places on upper ridges or ridgetops. Because we do not have replicates yet and only one small open site to compare, we cannot determine whether the level of "openness" or canopy bulk density of 0.12 would be sufficient to affect change in fire behavior in similar wildfire conditions.

Third, although there are theoretical and technical issues with quantifying the relationships between heat flux measurements and fireline intensity, our heat flux measurements did indicate a substantial component of convective heat transfer. Current fire behavior models incorporate convective transfer in various ways but often as a more minor component or as a cooling mechanism. We believe that in wind driven fires, or those on steep slopes or in "chimney" or other topography that funnel pressure or wind, that convective transfer is a key mechanism of heat transfer in wildfires. More work is needed to quantify and understand the relative role of convective transfer. For firefighters that utilize fuel treatments in suppression, this is particularly key, since convective heat transfer is a key safety concern and more difficult to predict in the field than radiant transfer.

### *3.3. Technology Transfer*

An extensive amount of technology transfer has been conducted for this project. This included numerous direct communications with firefighters and fire managers while on wildfires in the several years prior, during and after the study. The technology transfer or communication with fire incident management teams, before the project was funded, were critical in gaining support from the incident management teams and development of procedures for working with them on fires that have been very successful. As a result, even before the project commenced, several hundred firefighters and fire managers were aware of the proposed project. In addition, more traditional means of technology transfer were employed, including the following:

**Website**
**http://www.fs.fed.us/adaptivemanagement/projects/rapid_response/index.shtml**

**Manuscript for Publication**

"In-Situ Measurement of Fire Behavior during a Crown Wildfire in Relation to Fuels: a Case Study on the Black Mountain II Fire, Montana USA" is in the final stages of preparation for submission to International Journal of Wildland Fire.

**Presentations**

USFS National Fire Directors Meeting Fall 2004
International Fire Conference – Orlando 2003
Quincy Library Group – Winter 2004
California Fuels Committee (USFS) – several times
NPS Western Region Fire Management Officers – 2003
California-Nevada-Hawaii Forest Fire Council – 2004
Region 5 USFS Fire & Aviation Management Board of Directors- 2004
Region 5 Hotshot Workshop – 2004
Rx510 course in Arizona-nationwide, interagency – 2004
National Fire Academy-Advanced Fuels Section – 2004
California Interagency Incident Management Team Meetings – 2002, 2003, 2004
Informal discussions on 10 wildfires and over 5 prescribed burns

# 4. Conclusions

### *4.1. Summary of Operations, Logistics and Probability of Data Collection*

While the proportion of fires that we were able to capture fire behavior on was low, this was a huge achievement because of the previous lack of data collection during intense wildfire behavior. We feel this success is due in large part to our extensive coordination with incident management teams and our internal structure that incorporates experienced firefighters and Incident Management Team members on the project. We have developed other procedures and modified our approach to increase the probability on future related projects. This includes having a larger response team with squads that can split up, having more sensors, and being able to track predicted weather more rapidly. We feel that our approach of exceeding minimum requirements for fire operations in working with Incident Management Teams is also a key to our past and future success. When we approach an incident management team with one or more active, Division Supervisor qualified overhead, we are able to access any area of the fire we need to and can do so safely.

The expense of doing this type of work is greater than originally anticipated by the Joint Fire Science (JFS) board. We were able to get support from fire management to fill in the gaps. Smaller teams reduce the probability of data capture. Less equipment has the same result.

Despite the low probability of data capture, the data collected was extremely valuable because it included wildland crown fire behavior. These are the conditions when fuel treatments are most needed to work. Fire managers have recognized the value, despite the low probability of success. Not only have they made this clear to us, but have provided support, where they can, in purchasing associated equipment and funding us to do related monitoring work. This has included the Region 5 Fire Director for the USDA Forest Service (USFS), the Fire Director for the Western Region of the National Park Service, and the USFS Assistant Director for Operations in the Washington Office. We feel it will be important for the Joint Fire Science

Program to support similar future work, particularly of a group like ours that has such widespread support of fire managers at all levels in agencies and that has a proven track record of working safely and effectively on wildfires.

Although we have only begun to address the original objectives and would need more data to fully answer them, we have made a significant initially start. Since land managers must treat fuels to withstand and predict fire behavior across different vegetation and fuel settings under conditions of high intensity and often crown fire conditions, it is important to continue to learn more about fire behavior in relation to fuels in these conditions. It is not possible to address these needs completely in a burn chamber or even on most prescribed burns. The Canadian crown fire and Frostfire experiments provided valuable information but still cannot replicate the conditions that are found in free burning wildfires, such as we captured.